EFFECT OF THE NUCLEUS ON π^0-MESON PRODUCTION

V. S. DEMIDOV, E. D. ZHIZHIN, V. G. KIRILLOV-UGRYUMOV, A. K. PONOSOV, F. M. SERGEEV, and Ya. Ya. SHALAMOV

Institute of Theoretical and Experimental Physics; Moscow Institute of Engineering and Physics

Submitted to JETP editor March 7, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 437-442 (September, 1963)

Production of π^0 mesons in collisions of 2.8 GeV/c π^- mesons with light nuclei (C, Cl, F) and xenon nuclei was studied. The obtained angular distributions are compared with data on π^0 meson production on free and quasi-free nucleons at the same primary energy. The differences observed can be explained by the effect of the nucleus as a whole.

1. INTRODUCTION

In studies of elementary meson-nucleon interactions, in particular, with the aid of heavy-liquid bubble chambers (propane, xenon, freon mixtures, etc.), one usually selects cases of collisions with free or weakly bound nucleons of the nuclei and neglects the possible influence of the nucleus. However, several authors [1,2] have observed effects in interactions of high-energy primary particles with nuclei which indicate that the nucleus has a number of interesting little-studied properties affecting the elementary meson-nucleon collision. In particular, it is an open question whether or not the nucleus affects the percentage of peripheral interactions.

The aim of the present experiment was to examine the influence of the nucleus on the angular distributions of π^0 mesons produced in interactions with nuclei.

2. EXPERIMENTAL ARRANGEMENT

With the aid of a 17-liter bubble chamber [3] filled with a mixture of freon-12 and freon-13 and also a two-liter xenon chamber [4], we studied reactions of the type

$$\pi^- + A \rightarrow A' + m\pi^0, \qquad (1)$$

where A′ denotes all reaction products apart from π^0 mesons and A denotes the nucleus of the liquid filling the chamber.

The chamber was exposed to a beam of 2.8-GeV/c π^- mesons without a magnetic field. We selected all interactions of primary π^- mesons with nuclei of the chamber liquid accompanied by electron-positron pairs or single electrons whose directions led back to the point of interaction. The photographs were scanned independently by two observers.

3. ANGULAR DISTRIBUTION OF γ QUANTA

The obtained angular distributions of the γ quanta arising from the decay of π^0 mesons produced in reaction (1) were checked for effects connected with the efficiency of recording events in the fiducial volume of the chamber.

A correction was introduced in two ways:

1. For each γ quantum we measured the distance L from the star from which this quantum was emitted to the boundary of the fiducial volume of the chamber where it could have still been recorded. From the known conversion length L_c for the chamber liquid, we determined the size of the correction (ϵ) for the efficiency of recording the γ quantum emitted from the point of interaction at the given angle. Here we used the relation

$$\varepsilon = 1/[1 - \exp(-L/L_c)].$$

2. A second way of introducing corrections involved the calculation of the quantity ϵ on an electronic computer by simulating the process with the use of the actual distribution of the π^- beam along the chamber. For γ quanta emitted at angles up to $\sim 60°$ in the laboratory system the results obtained by both methods were practically the same; for larger angles, the computer calculations gave a somewhat lower value of ϵ in comparison to the first method. The dependence of the correction for the efficiency of recording γ quanta on the emission angle obtained by each method is compared in Fig. 1.

The corrected angular distributions for freon- and xenon-filled chambers are shown in Figs. 2 and 3, respectively. Both distributions were recalculated to the c.m.s. of the primary pion and nucleon to facilitate comparison with data on π^0 production on individual nucleons.

It is seen from the figures that the angular dis-

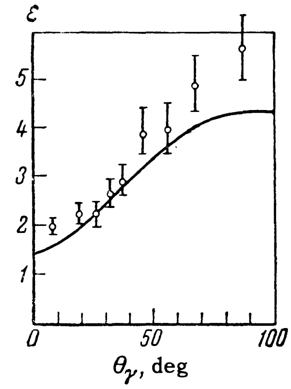

FIG. 1. Variation of the correction for the efficiency of recording γ quanta (ϵ) with the l.s. emission angle θ_γ of the γ. The solid curve represents the correction calculated on an electronic computer.

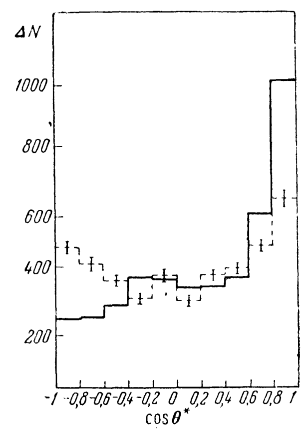

FIG. 2. Angular distribution of γ quanta from π^0 mesons produced in nuclei of the freon mixture. The angle θ^* is the c.m.s. emission angle of the γ in the center of mass of the meson-nucleon system (1001 quanta); the solid-line histogram represents the overall distribution for reactions (2)–(7) (1381 quanta). Both histograms have been corrected for the efficiency of recording γ quanta and have been normalized to the same area.

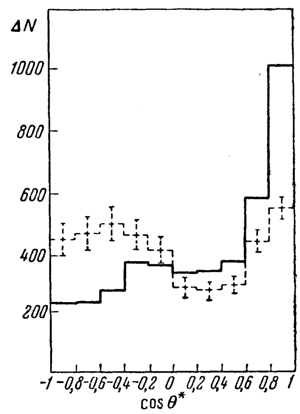

FIG. 3. Angular distribution of γ quanta from π^0 mesons produced in xenon nuclei (812 quanta); the solid-line histogram represents the overall distributions for reactions (2)–(7).

tributions have a dip close to γ emission angles of 90° and rise for angles close to 0 and 180° in the πN c.m.s. The ratio of the number of γ quanta emitted in the forward hemisphere to the number emitted in the backward hemisphere was 0.8 ± 0.19 for freon mixtures and 1.18 ± 0.22 for xenon (the errors are statistical).

Shown for comparison on the same figure is the angular distribution of γ quanta from π^0 mesons produced in πN collisions (all histograms have been normalized to the same area). To obtain this distribution, we made use of results obtained previously[5-7] in studies of the following reactions:

$$\pi^- + p \to m\pi^0 + n, \tag{2}$$

$$\pi^- + p \to \pi^- + \pi^0 + p, \tag{3}$$

$$\pi^- + p \to \pi^- + \pi^0 + \pi^0 + p, \tag{4}$$

$$\pi^- + n \to \pi^- + n + m\pi^0, \tag{5}$$

$$\pi^- + p \to \pi^- + \pi^+ + n + k\pi^0. \tag{6}$$

In addition, we investigated the reaction

$$\pi^- + n \to \pi^- + \pi^- + p + m\pi^0, \quad m = 1, 2, 3. \tag{7}$$

For this, we analyzed pictures obtained with the 17-liter freon chamber. We selected cases in which one of the particles stopped in the chamber or had an ionization 4–6 times minimum and was identified as a proton from the range, ionization, and multiple Coulomb scattering; the remaining particles either were of minimum ionization or stopped in the chamber and were identified as pions. For this analysis, we introduced corrections similar to those described above. The angular distributions for reaction (7) with the emission of one or more γ quanta are shown in Figs. 4 and 5.

To obtain the overall distribution of π^0 mesons produced in πN collisions, we combined the angular distributions for reactions (2)–(7) with weights calculated by Maksimenko[8] on the basis of statistical theory with allowance for isobar production. The ratio of the number of γ quanta emitted in the forward hemisphere to the number emitted in the

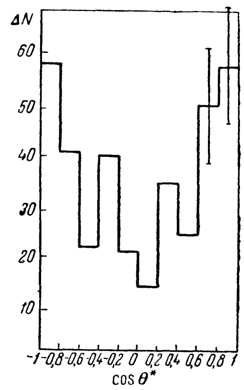

FIG. 4. Angular distribution of γ quanta from the reaction $\pi^- + n \to \pi^- + \pi^- + p + \gamma$ in the center of mass of the meson-nucleon system (112 quanta). The histogram has been corrected for the efficiency of recording γ quanta.

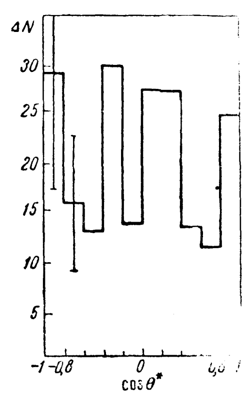

FIG. 5. Angular distribution of γ quanta from the reaction $\pi^- + n \to \pi^- + \pi^- + p + m\gamma$ (m = 2, 3) in the center of mass of the meson-nucleon system (70 quanta). The histogram has been corrected for the efficiency of recording γ quanta.

opposite direction determined from the overall distribution was $\Delta N_f/\Delta N_b = 1.81 \pm 0.41$, i.e., approximately twice as great as in the case of π^0 mesons produced in nuclei.

4. DISCUSSION OF RESULTS

From the histograms shown in Figs. 2 and 3, it is seen that the angular distributions of the γ quanta (π^0 mesons) produced in reaction (1) in nuclei of the freon mixture and of xenon differ from the overall angular distribution of γ quanta (π^0) for reactions (2)—(7), which involve individual nucleons.

The angular distribution of π^0 mesons produced on free nucleons has a sharp peak in the small-angle region. As already noted, the ratio of the number of π^0 mesons emitted in the forward hemisphere to the number emitted in the backward hemisphere is close to two, while the number of π^0 mesons in the angular interval 0—40° is five times as great as the number of π^0 mesons in the 140—180° interval. The angular distribution for π^0 mesons produced in nuclei is much smoother (the forward-backward ratio is ~ 1), and for light nuclei (C, Cl, F) and xenon, the character of the dependence is the same.

Hence we can conclude that the contribution of "peripheral" interactions for reactions in nuclei is considerably smaller than the contribution in reactions involving individual nucleons, while the contribution from "isobaric" interactions leading to the production of π^0 mesons in the backward hemisphere increases.

Such a change in the angular distributions of π^0 mesons produced in nuclei could be accounted for by cascade interactions with nucleons of the nucleus, although here the weak dependence of the angular distributions on the atomic number of the nucleus is not understood. Another possible explanation of the observed experimental results can be found in the fact that for incident pion energies of ~ 3 GeV, the diffraction mechanism for π^0 production begins to play a role. Here we can no longer consider the process for the production on nuclei as a process involving individual nucleons of the nucleus. Under these conditions, the pion interacts with the nucleus as a whole or rather with individual parts of it containing a large number of nucleons. The mean number of charged particles emitted from the point of interaction for freon mixtures is four, of which (for identified stars) two are protons. This apparently is not in contradiction with the foregoing remarks.

It should be noted that the obtained experimental results cannot be employed for quantitative conclusions. For the angular distribution of π^0 mesons produced on individual nucleons, we did not take into account the possible reactions

$$\pi^- + p \to \pi^- + p + 3\pi^0\ (4\pi^0), \tag{8}$$

$$\pi^- + p \to \pi^+ + \pi^- + \pi^- + p + m\pi^0, \tag{9}$$

$$\pi^- + n \to \pi^+ + \pi^- + \pi^- + n + m\pi^0, \tag{10}$$

$$\pi^- + n \to \pi^+ + \pi^- + \pi^- + \pi^- + p + \pi^0, \tag{11}$$

$$m = 1, 2, 3.$$

Crude estimates indicate that these reactions can give a contribution of from 15 to 20% and, possibly, somewhat smooth out the angular distribution. Hence further studies in this direction are necessary, in particular, with the use of bubble chambers placed in a magnetic field.

It is also of interest to draw some conclusions from the analysis of reaction (7). As already noted, we constructed the angular distributions of the emitted γ quanta separately for cases with one γ and more than one (here we refer to the number of γ quanta before the introduction of corrections for the efficiency) (Figs. 4 and 5). Allowance for the efficiency of recording γ quanta indicates that the distribution for single γ quanta practically coincides with the distribution of π^0 mesons produced in the reaction

$$\pi^- + n \to \pi^- + \pi^- + p + \pi^0. \tag{12}$$

More than three γ quanta were not observed in reaction (7).

The ratio of the number of single γ quanta emitted forward to the number emitted backward was 0.97 ± 0.35; in the case of the emission of two or three quanta this ratio was 1.02 ± 0.45. Here the angular distribution of the single γ quanta had a dip close to the angle 90° in the πN c.m.s. and was symmetric relative to this angle. The distribution for two and three γ quanta can be considered to be practically isotropic.

We could attempt to explain the angular distribution of the single γ quanta by assuming a uniform contribution of "peripheral" and "isobaric" π^0 mesons in reaction (12). In the c.m.s. of the πN collision, the former are emitted in the forward hemisphere while the latter are emitted backward. For agreement with the angular distribution, it is necessary to assume that the contribution of "peripheral" (and "isobaric") π^0 mesons is $\sim 30\%$.

The angular distribution for reactions with two and three γ quanta are in qualitative agreement with the statistical theory of high-multiplicity processes, according to which this distribution should be isotropic in the πN c.m.s.

The results obtained are in good agreement with earlier work on π^0 production at almost the same energies.[7,9-11]

In conclusion, we take this opportunity to express our gratitude to I. L. Rozental' and V. M. Maksimenko for helpful advice and discussions and to V. A. Kutilina for aid in the measurements. The authors are grateful to E. V. Kuznetsov for supplying the pictures for analysis and for valuable comments.

[1] Kuznetsov, Kuznetsov, Shalamov, and Grashin, JETP **42**, 1675 (1962), Soviet Phys. JETP **15**, 1163 (1962).

[2] Abbattista, Biasko, Mongelli, Romano, Waloschek, and Perez-Ferreira, Nuovo cimento **23**, 1 (1962).

[3] Blinov, Lomanov, Meshkovskiĭ, Shalamov, and Shebanov, PTÉ, No. 3, 35, 1958.

[4] E. V. Kuznetsov and I. Ya. Timoshin, PTÉ, No. 4, 40, 1959.

[5] Ya. Ya. Shalamov and V. A. Shebanov, JETP **39**, 1232 (1960), Soviet Phys. JETP **12**, 859 (1961).

[6] Ya. Ya. Shalamov and A. F. Grashin, JETP **42**, 1115 (1962), Soviet Phys. JETP **15**, 770 (1962).

[7] Bayukov, Leksin, and Shalamov, JETP **41**, 1787 (1961), Soviet Phys. JETP **14**, 1270 (1962).

[8] V. M. Maksimenko, Thesis, Physics Institute, Academy of Sciences, 1960.

[9] W. P. Walker, Phys. Rev. **108**, 872 (1957).

[10] Birger, Wang, Wang, Ting, Katyshev, Kladnitskaya, Kopylova, Lyubimov, Nguyen, Nikitin, Podgoretskiĭ, Smorodin, Solov'ev, and Trka, JETP **41**, 1461 (1961), Soviet Phys. JETP **14**, 1043 (1962).

[11] Bozóki, Fenyves, Frenkel, Gombosi, and Syrányi, Nuovo cimento **24**, 29 (1962).

Translated by E. Marquit
81